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Human Factors Analysis of Aircrew Operational Tasks in a Fixed-Wing Search and Rescue Aircraft Cargo Compartment

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Defence R&D Canada

Technical Memorandum

DRDC Toronto TM 2011-071

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Canada

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans.

Abstract

The Joint Operational Human Sciences Centre (JOHSC), at the request of Director Air Requirements (DAR), conducted a human factors analysis of aircrew operational tasks in a Fixed-Wing Search and Rescue (FWSAR) aircraft cargo compartment. The aim of this study was to provide guidance on minimum cargo compartment dimensions based on operational duties performed by Search and Rescue Technicians (SAR Techs). Specifically, it includes an analysis of the entire workspace envelope, to determine compartment length, width and height requirements. A secondary aim was to address concerns regarding future risk of musculoskeletal injury to SAR Techs working in the cargo compartment of a FWSAR aircraft.

The full range of operational tasks performed by SAR Techs in the current FWSAR aircraft was observed at squadrons in Trenton, Ontario and Comox, British Columbia. Space critical aerial delivery tasks and four relevant types of equipment were selected for analysis, including postural and spinal load assessments of manual materials handling (MMH) and anthropometry based on current SAR Tech demographics. The potential risk of musculoskeletal injury to SAR Techs during operational tasks was evaluated. The results were used to provide guidance based on ergonomics principals, standards in the industry, and current operational FWSAR procedures. Relevant anthropometry, personal protective equipment (PPE) and workspace dimensions were considered.

Based on a 99th percentile SAR Tech male (BoSS XXI), a minimal cabin compartment height of 198.7 cm, or rounded up to 200 cm, is recommended. However, this value does not account for any head room clearance required under turbulent conditions. Rapid Entire Body Assessment (REBA) and QBack analysis results indicate that the postural and loading demands were well above those accepted based on ergonomics practice and occupational limitations according to the National Institute for Occupational Safety and Health (NIOSH) guidelines. Reductions in potential musculoskeletal injury could be achieved by allowing SAR Techs to carry loads in a neutral (i.e., upright) posture. To mitigate musculoskeletal risk, it is advisable that education on proper load handling techniques be administered to SAR Techs.

Résumé

Le Centre interarmées des sciences humaines opérationnelles (CISHO), à la demande du Directeur, Besoins aérospatiaux (DBA), a effectué une analyse des facteurs humains liés aux tâches opérationnelles qui sont exécutées par les membres d'équipage dans la soute des avions de recherche et de sauvetage (SAR). L'étude avait pour objet d'établir des lignes directrices quant aux dimensions minimales de la soute compte tenu des tâches opérationnelles exécutées par les techniciens de recherche et de sauvetage (Tech SAR). Plus particulièrement, l'étude comprend une analyse de l'ensemble de l'espace de travail afin de déterminer la longueur, la largeur et la hauteur que devrait avoir la soute. Un objectif complémentaire consistait à se pencher sur le risque futur que les Tech SAR travaillant dans la soute d'un avion SAR subissent des blessures musculo-squelettiques.

On a observé toute la gamme de tâches opérationnelles exécutées par les Tech SAR dans les avions SAR actuels, dans les escadrons de Trenton (Ontario) et de Comox (Colombie-Britannique). On a choisi des tâches dont l'exécution en vol nécessitait un espace critique ainsi que quatre types d'équipements pertinents pour les analyser, notamment évaluer l'effort postural et vertébral lié à la manutention manuelle des matériaux (MMM) et établir une anthropométrie fondée sur des données démographiques courantes des Tech SAR. On a également évalué le risque que des Tech SAR subissent des blessures musculo-squelettiques durant l'exécution de tâches opérationnelles. Les résultats ont été utilisés pour établir des lignes directrices fondées sur des principes d'ergonomie, des normes de l'industrie et les procédures d'exploitation actuelles des avions SAR. On a tenu compte de données anthropométriques pertinentes, des tendances de la croissance séculaire, de l'équipement de protection individuelle (EPI) et des dimensions de l'espace de travail.

En se fondant sur le 99^{e} percentile de Tech SAR masculin (BoSS XXI), on recommande que la soute mesure au moins 198,7 cm de hauteur, valeur pouvant être arrondie à 200 cm. Toutefois, cette valeur ne tient pas compte du dégagement au-dessus de la tête qui est nécessaire en présence de turbulences. Les résultats des analyses effectuées à l'aide d'outils d'évaluation (Rapid Entire Body Assessment [REBA] et QBack) indiquent que l'effort postural et vertébral nécessaire était bien supérieur à celui prescrit par les lignes directrices sur les pratiques d'ergonomie et les restrictions professionnelles publiées par l'Institut national pour la santé et l'hygiène professionnelles (INSHP). Il est possible de réduire les risques de blessures musculo-squelettiques en permettant aux Tech SAR de transporter des charges dans une posture neutre (c'est-à-dire debout). Pour atténuer le risque de blessures musculo-squelettiques, il est conseillé d'enseigner aux Tech SAR les bonnes techniques de manutention des charges.

Executive summary

Human Factors Analysis of Aircrew Operational Tasks in a Fixed-Wing Search and Rescue Aircraft Cargo Compartment:

Sub-Lt. Tracy Teeple; Lieut. Jason McHarg; Lieut. Lori Coady ; DRDC Toronto TM 2011-071; Defence R&D Canada –Toronto; January 2010.

Background: The National Research Council Canada (NRC) was contracted by the Department of Public Works and Government Services Canada to conduct an independent review of the Canadian Forces (CF) Statement of Operational Requirements (SOR) for the Fixed-Wing Search and Rescue (FWSAR) project. In their report, NRC recommended (among other things) that a supplementary study examining working postures assumed by Search and Rescue Technicians (SAR Techs) during in-flight operational duties was necessary to more fully establish the risk of musculoskeletal injury to SAR Techs in the cargo compartment workspace envelope. In accordance with the recommendations outlined by NRC, the Director Air Requirements (DAR) tasked the Joint Operational Human Sciences Centre (JOHSC) at Defence Research and Development Canada-Toronto (DRDC Toronto) to conduct further human factors analysis of aircrew operational tasks in a FWSAR cargo compartment. Due to the timelines imposed by this project, it was not possible to carry out all recommendations that NRC stipulated. Instead this DRDC Toronto study included a manual materials handling (MMH) assessment of the full range of operational tasks performed by SAR Techs in the current FWSAR aircraft. A secondary aim was to address concerns regarding future risk of musculoskeletal injury to SAR Techs working in a FWSAR aircraft cargo compartment.

Based on a review of scientific work previously conducted and information provided by DAR, it was determined that only space-critical operational tasks would be quantitatively analyzed as these jobs are the most physically demanding and require the largest workspace. The Rapid Entire Body Assessment (REBA) and QBack tools were selected to determine the potential risk of musculoskeletal injury for SAR Techs. The assessment methodology included task descriptions and postural analysis with respect to aerial delivery (preparation and deployment) of selected equipment: marine pump, toboggan, equipment bundle, and sea rescue kit. QBack was used to examine spinal joint loading with respect to the equipment bundle task.

Results: During in-flight manoeuvres, SAR Techs were observed performing operational procedures requiring forceful exertions and awkward postures, particularly when joint ranges of motion of the limbs and the body were restricted by the cargo compartment workspace. Further reductions to cargo door exit and aisle workspaces would elicit awkward postures. Based on the REBA scores obtained for each MMH task, the postural demands placed on SAR Techs were well above the acceptable upper limits based on industry-standard ergonomics guidance. It was demonstrated using QBack that the recommended occupational limitations for one-person static loads were exceeded based on the National Institute for Occupational Safety and Health (NIOSH) guidelines.

Other factors that are unique to the aviation work environment, which increase SAR Tech load bearing demands, are in-flight turbulence and the effect of gravitational (G) loading during aircraft turns. Personal protective equipment (PPE) and the height of night vision equipment were

also considered. In order to comply with occupational health and safety standards, it is therefore necessary to accommodate the physical workspace to the SAR Techs conducting heavy MMH of SAR equipment. Based on a 99th percentile SAR Tech male (BoSS XXI), a minimal cabin compartment height of 198.7 cm, or rounded up to 200 cm, is recommended. However, this value does not account for any head room clearance required under turbulent conditions.

Significance: The results of this study will provide DAR with human factors guidance on workspace dimension requirements for SAR Techs performing their occupational duties in a cargo compartment. These requirements will assist the Air Force to make informed decisions regarding specifications during procurement of a FWSAR aircraft in the future.

Sommaire

Analyse des facteurs humains liés aux tâches opérationnelles qui sont exécutées par les membres d'équipage dans la soute des avions de recherche et de sauvetage :

Ens 1 Tracy Teeple, Lt Jason McHarg, Lt Lori Coady, RDDC Toronto TM 2011-071, R & D pour la défense Canada – Toronto, mai 2011.

Contexte : Le ministère des Travaux publics et des Services gouvernementaux a attribué un contrat au Conseil national de recherches du Canada (CNRC) pour mener un examen indépendant de l'énoncé des besoins opérationnels des Forces canadiennes dans le cadre du projet d'avion de recherche et de sauvetage. Dans son rapport, le CNRC a recommandé, entre autres, de procéder à une étude complémentaire pour examiner les postures de travail que doivent assumer les techniciens de recherche et de sauvetage (Tech SAR) dans le cadre de leurs tâches opérationnelles en vol, en vue de mieux définir les risques de blessures musculo-squelettiques encourus par les Tech SAR dans l'ensemble de l'espace de travail compris dans la soute de l'avion. Conformément aux recommandations formulées par le CNRC, le Directeur, Besoins aérospatiaux (DBA), a chargé le Centre interarmées des sciences humaines opérationnelles (CISHO) de Recherche et développement pour la défense Canada – Toronto (RDDC) d'effectuer une analyse plus poussée sur les facteurs humains liés aux tâches opérationnelles qui sont exécutées par les membres d'équipage dans la soute des avions de recherche et de sauvetage (SAR). En raison des échéanciers imposés par le projet en question, il n'a pas été possible de donner suite à toutes les recommandations formulées par le CNRC. Au lieu de celles-ci, l'étude de RDDC – Toronto comprend une évaluation de la manutention manuelle des matériaux (MMM) de toute la gamme de tâches opérationnelles exécutées par les Tech SAR dans les avions SAR actuels. Un objectif complémentaire consistait à se pencher sur le risque futur que les Tech SAR travaillant dans la soute d'un avion SAR subissent des blessures musculo-squelettiques.

Après un examen des travaux scientifiques déjà effectués à cet égard et des renseignements fournis par le DBA, on a déterminé que seules les tâches opérationnelles nécessitant un espace de travail critique feraient l'objet d'une analyse quantitative, car ces tâches exigent un plus grand effort physique et un plus grand espace pour leur exécution. Des outils d'évaluation, comme le Rapid Entire Body Assessment (REBA) et le QBack, ont été choisis pour déterminer les risques de blessures musculo-squelettiques encourus par les Tech SAR. La méthode d'évaluation comprenait la description des tâches et une analyse posturale relative à l'exécution de tâches en vol (préparation et déploiement) à l'aide de certains matériels, comme de l'équipement de pompage de navire, des toboggans, des paquets de matériel et des trousses de sauvetage en mer. L'outil QBack a permis d'examiner l'effort sur les articulations vertébrales pendant l'exécution de tâches nécessitant l'utilisation du paquet de matériel.

Résultats : Durant les manœuvres en vol, on a observé des Tech SAR suivant des procédures opérationnelles qui commandaient un effort physique pénible et une mauvaise posture, tout particulièrement des cas où la portée des articulations des membres et du corps était restreinte par l'espace de travail dans la soute. D'autres restrictions découlant de la sortie par la porte de la soute et des espaces de travail dans les couloirs donnaient lieu à de mauvaises postures. Selon la

notation REBA obtenue pour chacune des tâches MMM, l'effort postural nécessaire aux Tech SAR pour l'exécution de celles-ci était bien supérieur aux limites maximales acceptables prescrites par les lignes directrices d'ergonomie normalisée de l'industrie. L'outil QBack a permis de démontrer que, selon les lignes directrices de l'Institut national pour la santé et l'hygiène professionnelles (INSHP), les limites professionnelles recommandées étaient dépassées en ce qui concerne les charges statiques pouvant être manipulées par une personne.

D'autres facteurs propres au milieu de travail aérien, comme les turbulences en vol et l'effet gravitationnel sur la charge durant les virages de l'avion font augmenter d'autant plus l'effort physique que doivent déployer les Tech SAR. Le port d'équipement de protection personnelle et la hauteur de l'équipement de vision nocturne ont également été pris en considération. Afin de respecter les normes d'hygiène et de sécurité au travail, il faut donc aménager un espace de travail permettant aux Tech SAR de manipuler l'équipement SAR lourd (MMM). Selon le 99e percentile de Tech SAR masculin (BoSS XXI), on recommande que la cabine mesure au moins 198,7 cm de hauteur, valeur que l'on peut arrondir à 200 cm. Toutefois, cette valeur ne tient pas compte du dégagement au-dessus de la tête qui est nécessaire en présence de turbulences.

Portée : Les résultats de la présente étude donneront au DBA une orientation sur les facteurs humains, notamment sur les dimensions que doit avoir l'espace de travail nécessaire aux Tech SAR pour exécuter leurs tâches professionnelles dans la soute d'un avion SAR. Ces exigences en matière de dimensions aideront la Force aérienne à prendre une décision éclairée quant aux spécifications nécessaires pour mener à bien tout futur processus d'acquisition d'avions SAR.

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The authors wish to acknowledge the assistance of personnel based at 424 (T&R) Squadron, 8 Wing CFB Trenton, Ontario and at 442 (T&R) Squadron, 19 Wing CFB Comox, British Columbia. The JOHSC team in particular acknowledges the SAR Techs for their professionalism and dedication in demonstrating the full range of operational tasks to the team. The JOHSC team would also like to thank MWO Timothy Eagle at Director of Personnel Generation Requirements (DPGR) for facilitating research efforts on the FWSAR project.

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1 Introduction

1.1 Background

The primary objective of Canadian Forces (CF) Search and Rescue (SAR) operations is to provide immediate emergency response to marine and aeronautical incidents and prevent human loss of life and injury in all Canadian landmass and coastal areas [ref 1]. In addition, Canada is an international contributor to a world class SAR system with responsibility for SAR response as far north as the North Pole and half way across the Atlantic Ocean. The entire SAR area of responsibility (AOR) is extensive and is serviced by five SAR squadrons located across Canada equipped with both fixed-wing (FW) and rotary-wing (RW) aircraft.

The CC-115 Buffalo and the CC-130 Hercules are the two aircraft types currently used in Fixed-Wing Search and Rescue (FWSAR). The aim of the FWSAR project is to acquire a fleet of replacement aircraft by 2015 [ref 2]. The new CF FWSAR aircraft will replace the Buffalo and Hercules aircraft in the primary SAR role, and it therefore must adhere to explicit operational objectives in order to maintain continued and effective provision of CF emergency SAR response services [ref 1].

In accordance with Aviation Occupational Safety and Health regulations [refs 3 and 4], the CF FWSAR Statement of Operational Requirements (SOR) has also stipulated the criteria for reasonable accommodation of Search and Rescue Technicians (SAR Techs) to safely perform their occupational duties in a FWSAR aircraft. The CF endeavours to comply with occupational health and safety standards and this duty applies to providing a safe work environment for aircrew personnel in an effort to mitigate exposure of physical hazards during operational and support activities [ref 1].

The mandatory requirements stipulated for the FW aircraft cargo compartment dimensions [ref 1] are stated below. In this context, the reference to “physiological injury” describes physical stressors in terms of musculoskeletal injury.

> Para 2.7.5: *The cargo compartment must be of sufficient, unobstructed width and height dimensions to provide the target population with the clearance necessary to safely perform all ground and airborne tasks.*
>
> *The cargo compartment width and height, and the load configuration of the SAR equipment, must combine to ensure the risk of physiological injury is minimal while ensuring that crewmembers can operate through the full range of their required duties without risk of long-term physiological effects.*

In Canada, the Aviation Occupational Safety and Health regulation provides the minimum health and safety standards for handling equipment by aircrew personnel and administrative actions undertaken to mitigate risks regarding Manual Materials Handling (MMH) on an aircraft [ref 3].

Occupational MMH refers to tasks that require lifting, lowering, pushing, pulling, carrying, and holding of loads. MMH activities are usually associated with risk factors or stressors in or arising from, the work environment and can include awkward postures, forceful exertions, repetitive motions, and mechanical or contact stress [ref 4]. These types of activities are often of concern when assessing job tasks for risks that have the potential to lead to injury of the tissues of the body (muscles, bones, ligaments, tendons, nerves, etc.) commonly known as musculoskeletal disorders (MSDs) [ref 5].

Workplace musculoskeletal disorders (WMSDs) are a major concern and are linked to cumulative physical stress of the body over time. Forced awkward postures are a common problem contributing to MSDs when working within restricted spaces. Musculoskeletal problems such as strength reduction, reduced force output of the back muscles, and higher shear and compression loading on the spine and have all been associated with reduced vertical workspaces [ref 6]. For example, some work procedures can oblige personnel to maintain postures for extended periods or execute movements quickly without adequate time for muscle recovery. Muscle fatigue from maintaining awkward positions within restricted work environments has been linked to increases in neck and shoulder musculoskeletal pain [ref 7]. In the case of the spinal column, approximately 20% of the compressive load is carried by the facet joints and 80% by the intervertebral disc. The problem with maintaining forward flexion for extended periods, as would be expected during SAR operations, is that the discs become loaded unevenly. When lifting in trunk flexion, distribution of spinal loading is altered and may be 2 to 3 times higher compared to neutral upright postures [ref 5]. Furthermore, the disc fluid can be become compressed towards the anterior aspect of the disc, resulting in facet joints taking on a greater share of the loading.

The discipline of human factors focuses on individuals and their interaction with products, equipment, facilities, procedures and working environments. The emphasis is on human engineering and how design influences people. As such, the human factors discipline seeks to change things individuals use and the environments in which they work to better match the capabilities, limitations, and needs of people [ref 8]. Within the human factors discipline, the workspace is often designed to accommodate the range between the 5^{th} and 95^{th} percentile to provide suitability to at least 90% of the female and male user population. However, adopting this strategy into design changes will exclude the 10% of personnel having anthropometric measures outside of this range, and may predispose them to undesirable health and safety risks. Therefore, for health and safety concerns, it is desirable to accommodate as much of the potential user population as possible.

In accordance with the CF' intent to voluntarily comply with industrial health and safety standards, the FWSAR SOR stipulates specific criteria relating to minimum cargo compartment dimensions (length, width, and height). Refs 4 and 9 were the two main human factors studies considered when conducting the present study, and provide a broader understanding of the scientific work previously conducted. Ref 4 indicates that the distance measured between the cargo compartment standing surface and the lowest ceiling obstruction should provide approximately 210 cm height clearance and 77.5 cm minimum aisle width. These measurements account for SAR Tech stature based on anthropometric data, personal protective equipment (PPE), and some of the aerial delivery and equipment preparation tasks. Ref 9 states a similar cargo compartment height and recommends specific workspace dimensions (i.e. length, width, and height) applicable to various operational tasks.

The National Research Council Canada (NRC) was contracted by the Department of Public Works and Government Services Canada to conduct an independent review of the CF SOR for the FWSAR project [ref 10]. In their report NRC recommended (among other things) that a supplementary study examining working postures assumed by SAR Techs during in-flight operational duties was necessary to more fully establish the risk of musculoskeletal injury to SAR Techs in the cargo compartment workspace envelope. In accordance with the recommendations outlined by NRC, the Director Air Requirements (DAR) tasked the Joint Operational Human Sciences Centre (JOHSC) at Defence Research and Development Canada-Toronto (DRDC Toronto) to conduct further human factors analysis of aircrew operational tasks in a FWSAR cargo compartment. A workspace envelope is the three-dimensional (3D) space that is reasonably safe for personnel, whether seated or standing, performing some type of manual handling task with the hands [ref 8].

1.2 Search and Rescue Technicians

There are approximately 160 SAR Techs currently serving in the CF. Each aircraft deployed on a SAR mission includes a team of at least two SAR Techs. SAR Techs are physically fit and are required to meet the Physical Fitness Maintenance Program (PFMP) evaluation standard [ref 11]. They are highly trained specialists who regularly perform physically demanding tasks during SAR operations and training. Approximately 50% of their job requires lifting, carrying, and dragging heavy awkward loads such as air droppable equipment (e.g., marine pump, toboggan, stretcher, equipment bundle, sea rescue kit) while wearing heavy cumbersome clothing [ref 12]. Depending on the nature of the SAR tasking and geographical location, clothing items such as immersion suits and cold weather gear may be combined with parachutes, medical kits, and other survival / rescue equipment.

SAR training is extensive and is comprised of advanced trauma life-support to a paramedic standard, land and sea survival, and specialized rescue techniques. The SAR operational and training tasks subject SAR Techs to a high risk of personal injury. For example, SAR Techs are exposed to adverse working conditions with respect to environmental and physical stressors [ref 12]. Specifically, the work environment demands in-flight exposure to factors such as extreme climatic conditions, noise, vibration, and gravitational (G) forces.

The procedures that SAR Techs perform have been developed from long-term operational experience and are designed to minimize risk of mission failure. The Air Force regularly reviews and improves SAR procedures as necessary. The procedures that SAR Techs perform embody proven life saving techniques, which must be adhered to in the future context of FWSAR. As such, SAR Techs must be able to successfully complete the full range of current operational FWSAR procedures. Their failure to be able to accomplish tasks has the potential to jeopardize mission objectives and the consequence of error constitutes unacceptable risk to distress victims.

1.3 Aim

The aim of this study was to provide guidance on the minimum cargo compartment space requirements based on operational duties performed by SAR Techs. Specifically, it includes an analysis of the operational workspace envelope in order to determine the minimum cargo compartment length, width, and height requirements. A secondary aim was to address concerns regarding future risk of musculoskeletal injury to SAR Techs working in a FWSAR aircraft cargo compartment.

2 Methodology

2.1 Setting

Preliminary information pertaining to the workspace envelope of the current FWSAR aircraft was obtained by means of equipment and procedure familiarization to allow JOHSC analysts the opportunity to ask squadron personnel questions, video record the workspace layout, and obtain objective measurements. Over the periods of 21-25 June 2010 and 4-10 July 2010, SAR Techs working on current FWSAR aircraft participated in a human factors study to assess space requirements for current SAR operational tasks. The study was approved by the DRDC Human Research Ethics Committee (HREC) and informed voluntary consent was obtained by each of the SAR Tech participants. 31 participants were recruited for the video data capturing portion of this study. This includes all personnel who may have been video recorded during the field trials. Data was collected at two separate locations: 424 Transport and Rescue (T&R) Squadron, 8 Wing, CFB Trenton, Ontario and 442 (T&R) Squadron, 19 Wing, CFB Comox, British Columbia. These squadrons are equipped with the CC-130 Hercules or CC-115 Buffalo aircraft and each represented different cargo compartment layouts and equipment configurations. This provided the JOHSC analysts with a representative sample of the physical space where SAR Techs work, as well as their work activities.

2.2 Data collection

SAR Tech duties were captured using digital recording devices during in-flight operations. The analysis considered the entire workspace envelope, including the dimensions of the aisle and cargo door exits, required for MMH of SAR payload and aerial delivery equipment. The method employed in the acquisition of data included qualitative and quantitative postural assessment of SAR Techs performing MMH tasks. The space-critical tasks identified for analysis included preparation and deployment of the marine pump, toboggan, equipment bundle, and the sea rescue kit as these jobs are the most physically demanding and require the largest workspace. These tasks were captured by video in-flight and the recordings were used for subsequent analysis.

The demands of each task (body postures, loads, frequencies) were assessed using Rapid Entire Body Assessment (REBA) and QBack tools. Information pertaining to instrumentation and assessment tools can be found in Annex A.

A mock up static display was designed to represent the FWSAR aircraft cargo compartment in a controlled environment. The workspace envelope was defined by a drop ceiling constructed to represent the minimum vertical height and a floor grid to represent the minimum width and length dimensions. The display configuration was based on the minimum workspace dimensions (length, width, and height) provided in the SOR [refs 1 and 9] required for SAR aerial equipment preparation and deployment. Two SAR Techs were recruited to participate in the mock up trials. The height and weight of one of the SAR techs was recorded.

The bundle drop task was selected as the task for this trial as it is the least demanding of the four. The total bundle drop load was measured as 71 kg and was being carried by the two participants for the mock up trial. It is assumed that this load was evenly distributed between the two participants involved, and that an equal portion of the weight (approximately 17.9 kg) was held by each hand. This assumption is made because it was not possible to measure directly the load carried in each hand.

A biomechanical analysis using QBack was performed on this MMH task to demonstrate the risk of musculoskeletal injury. The results of the biomechanical analysis were compared to the National Institute for Occupational Safety and Health (NIOSH) guidelines for MMH.

For anthropometric discussions an attempt was made to acquire up-to-date stature measurements on CF personnel from several different sources. Stature was defined as the vertical distance between the bottom of the feet and the top of the head while standing [ref 2].

3 Results

3.1 Rapid Entire Body Assessment (REBA)

REBA scores and the degree of risk levels are shown in *Table 1*. The level of MSD risk ranges between 1 and 15 with 1 being "negligible" risk and 11-15 being "very high risk". The results of the full REBA analysis, including task descriptions, REBA scores and the respective risk level can be found in Annex B.

Table 1: Rapid Entire Body Assessment (REBA) for 4 types of aerial delivery SAR equipment.

		Marine Pump		***Toboggan***		***Equipment Bundle***		***Survival Rescue Kit***	
		Ramp	Cargo	Ramp	Cargo	Ramp	Cargo	Ramp	Cargo
Buffalo CC-115	**REBA**	10.5	11.5	12	11	10.5	11.5	12	12
	Risk Level	High	Very High	Very High	Very High	High	Very High	Very High	Very High
Hercules CC-130	**REBA**	10.5	--	--	--	12.5	--	12	--
	Risk Level	High	--	--	--	Very High	--	Very High	--

The REBA score and risk level are shown for single common tasks (aerial delivery) for 4 types of SAR equipment. These tasks were analyzed at the ramp and cargo door exits in the Buffalo and Hercules aircraft. Note: SAR tasks not analyzed directly are indicated by a dash.

3.1.1 Marine pump

The postural demands associated with marine pump preparation and deployment at the Buffalo ramp and cargo door exits are high according to the REBA scores. The composite scores for the Buffalo ramp and cargo door exits were 10.5 and 11.5, respectively indicating high to very high level of risk. A similar composite score of 10.5 was obtained at the ramp of the Hercules.

3.1.2 Toboggan

The REBA scores for toboggan preparation and deployment at the Buffalo ramp and cargo door exits were 12 and 11, respectively, indicating a very high level of risk.

3.1.3 Equipment bundle

The REBA risk level for the bundle drop ranged from high to very high level of risk. The equipment bundle drop was identical for both aircraft; however, SAR Techs of the respective aircraft types used different techniques to deploy the equipment. The composite scores for the Buffalo ramp and cargo door exits were 10.5 and 11.5, respectively. A composite score of 12.5 was obtained at the ramp of the Hercules, indicating a very high level of risk.

3.1.4 Survival rescue kit

The survival rescue kit consisted of four bundles that were positioned and secured to the aircraft. The REBA score was 12, regardless of the aircraft type and point of exit, indicating a very high level of risk.

3.2 Biomechanical analysis (QBack)

According to the NIOSH, the maximum recommended load lifted by a two-person team is 34.5 kg [ref 13]. The resultant compressive loads on the lumbar discs of approximately 3400 N [ref 13] or less can be tolerated by most individuals. As shown in Figure 1, the estimated compressive force using QBack was 6115 N, and is well above the NIOSH action limit of 3433 N.

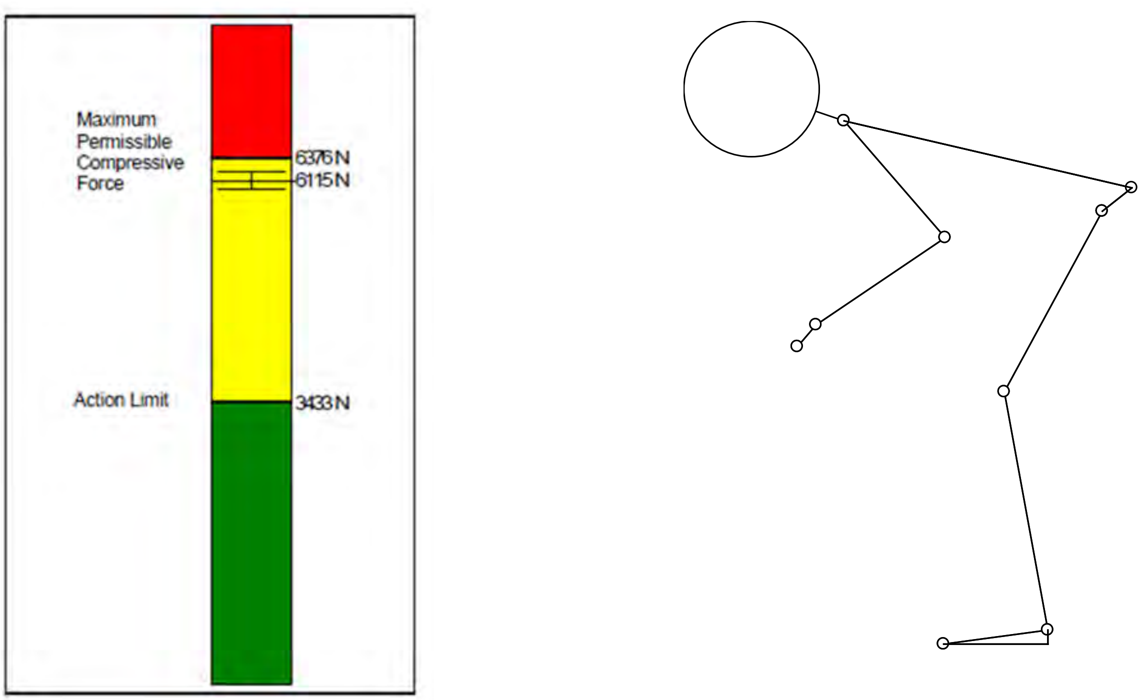

Figure 1: Illustrative QBack symmetrical load analysis for lift of 17.9 kg bundle from each hand.

3.3 Anthropometry

The height and weight of the SAR Tech participant used in the mock-up trial placed him as a 99th percentile male measuring 190.5 cm in stature and 105.2 kg mass according to CF Land Force Anthropometric Survey. Several anthropometric databases were collected for CF personnel. First, anthropometric data were collected from the BoSS XXI system of which 3,452 recent scans of CF personnel were obtained. A second source was stature measurements of the current CF SAR Tech population taken manually by a member of the Director of Soldier Systems Program Management (DSSPM).

4 Discussion

4.1 Rapid Entire Body Assessment (REBA)

The REBA tool was used to examine postures assumed by the SAR Techs during preparation and deployment tasks at two separate cargo compartment exits and aircraft types. The results of the REBA assessment reveal high to very high levels of musculoskeletal risk to the SAR Techs regardless of the aircraft type or point of exit [ref 14]. During lifting, lowering, and carrying of SAR equipment, SAR Techs developed large postural asymmetries, particularly at the Buffalo CC-115 cargo door exit. In a situation where aisles are too narrow or the physical space is constrained, aircrew will adopt whatever posture is required to get the task done. It is essential then to provide adequate space for aircrew for handling of equipment and to allow free volume of body movements during operational and maintenance tasks under both normal and emergency conditions. There is considerable epidemiological evidence associating occupational risk factors such as heavy physical work, lifting and forceful movements, bending and twisting (awkward postures), and whole-body vibration to MSDs [refs 5 and 6]. The term “awkward posture” is used broadly to include work involving bending at the waist with straight legs (stooped), bending of the knees with the buttocks resting on the heels (squatted), non-neutral trunk postures, and lifting. These types of postures in occupational settings, where restricted workspaces predominate, have been observed for aircraft cargo holds [ref 6], mining [refs 15, 16, 17] and utility tunnels [ref 18].

The minimum width of a workspace should be determined by the space required by a team carrying the load. A two-person team should ideally carry loads side-by-side and facing the same direction. However, teams of two SAR Techs were frequently observed carrying loads in single file with the lead SAR Tech walking ahead of the load in the aisle and at cargo door exits. This practice obliged the lead SAR Tech to hold the load behind his/her back, which produced awkward lower and upper limb postures. Other undesirable postures observed during load carriage activities were extreme bending, twisting, and holding the load too far away laterally from the body. It is recognized that the engineering practicalities of having two SAR Techs carrying a long object between them (i.e., a toboggan) side-by-side inside some airframes may not be practical. However, these asymmetrical load-bearing (twisting forces) are a risk factor for MSDs and should be avoided as much as possible when designing the SAR Tech workspace envelope.

4.2 QBack

The QBack tool was used to demonstrate the compressive loads at the back during a bundle drop task. In this model, the NIOSH Action Limit (AL) suggests that the task represents a normal risk to most individuals whereas the Maximum Permissible Limit (MPL) represents the point at which musculoskeletal injury rates increase significantly. The area between the AL and MPL represents the zone where administrative or engineering controls may be required as these lifting conditions may be unacceptable for some individuals. The NIOSH standard is normally applied to ideal lifting conditions and does not account for other risk factors or stressors in, or arising from, the work environment such as unequal contribution of loads, poor force coupling between the hands and load, and asymmetrical working postures, all of which may be at play here. High compression forces at the spine have been observed in stooped postures during sustained or repeated flexion postures and while working at or near the cargo compartment standing surface. These factors will have implications on the safe handling of SAR equipment in the cabin compartment workspace envelope.

Results of the QBack analysis show that the recommended occupational limitations for one-person static loads were exceeded. The geometry of the load to be lifted and trunk angle are among many variables that can influence the level of tissue stress at the back during MMH lifting tasks. The L4/L5 disc is the area of the spine located between the fourth and fifth lumbar vertebrae. There can be considerable compressive and shear forces generated on the vertebral bodies in this region by simply increasing weight and horizontal displacement of the load relative to the body. During heavy lifting, the back muscles must produce a moment to counteract the force produced by each hand. The risk of back injury increases as the distance between body and the hand load increases due to the greater moment arm and rotational stress. This is due to an increased force required to support a load with increased angle between the supporting limb and the vertical. In contrast to standing in an upright position, which brings the load closer to the body, bending forward at the hips can generate greater forces on the back and produce high tissue stress due to the difference in horizontal distance between the centre of gravity of the load and discs [ref 8].

It has been shown that working in stooped or squatted postures produces increased torque at the spine compared to upright standing postures. Compared to unloaded situations, the extent of spinal loading and tissue damage is directly linked to increased forces generated by the active trunk muscles [ref 18]. Several studies have also examined strength capacity (strength) losses between kneeling, stooping, and standing. A 10 to 20% reduction in lifting capacity was reported for jobs performed while kneeling due to loss of lower limb assistance than compared to stooping postures or standing upright [ref 19]. When this occurs a worker must work at a greater percentage of his/her maximal lifting capacity, which increases the risk of an over-exertion injury [ref 18].

It should be noted that the results of QBack are conservative in that they do not account for two factors such as team lifting and the carrying of loads in dynamic situations which increase the load experienced by the SAR Techs. In the first factor, the maximum load that can be lifted by a team, is less than the total loads that can be lifted by individuals [refs 20 and 21]. The QBack analytical tool was used to demonstrate that the SAR Tech tasks had already exceeded the NIOSH derived occupational load limitations. Previous work on strength capacity of lifting teams reveals that the combined strength of the team is less than the arithmetic sum of the individual strengths. In that analysis, for example, the strengths of a three-person team was reported as only 90% of the sum of the individual isometric strengths suggesting that the static strengths for individuals are not additive for the team in total [ref 20]. Given the frequency with which SAR Techs lift heavy loads as a team, the result is that the loss of total lifting capacity due to the team effect means that when lifting as a team the SAR Techs are further exceeding the recommended one-person load limitations.

As stated, the QBack load limitation analysis conducted was performed in a static environment. However, the second factor that further increases SAR Tech load bearing demands, and is unique to the aviation work environment, are in-flight turbulence and the effect of acceleration (or G) loading, typically during turns. Both of these effects are typically encountered while the SAR Techs are moving and preparing equipment for aerial delivery and the aircraft is manoeuvring to keep a drop zone or target in sight. During non-turbulent in-flight conditions, the static and dynamic load bearing tasks can be predictably performed in normal circumstances. However, turbulence causes a disruptive input to balance and stability, increasing the demand of the dynamic load due to the fact they have to readjust their posture in order to adapt to the changing dynamic forces and maintain stability. There is no quantitative analysis on the effects of turbulence that is directly applicable to measuring the impact on SAR Tech tasks. However, some accommodation should be made to account for the effects of turbulence as it relates to the risk of injury and further research is warranted.

G loading refers to the addition of accelerative forces beyond that due to gravity alone, and normal body weight is multiplied by the G force load factor in the z-axis. During low level SAR manoeuvring, it was anecdotally reported by SAR pilots and trial participants that the G factor experienced in the FWSAR aircraft can range from 1 G (in level flight) to 1.41 G (in a 45^{o} degree bank), although the effect can be even more pronounced during flight in proximity to challenging terrain in mountainous regions. The impact during a typical 45 degree bank turn is that the load force carried by the SAR Techs is increased by 41%, as is the weight of their own bodies. Thus, it becomes even more imperative that SAR Techs be provided as much opportunity as possible to manage their MMH tasks in a neutral body position.

4.3 Anthropometry

Because a person from any CF non-commissioned member trade could become a SAR Tech, it is logical that the full range of CF anthropometry should be considered. The BoSS XXI has proven to be fairly accurate when taking anthropometric measurements (refs 22 and 23). However, there are issues concerning selection bias and accuracy that, until answered sufficiently, make the BoSS XXI data questionable to be used in this way. Additionally, the DSSPM data may not conform to valid anthropometric measurement standards. Thus, the 1997 CF Anthropometric survey of the Land Forces remains the only valid anthropometric source for this work.

Earlier human factors studies suggest a minimum height clearance of approximately 210.0 cm between the cargo compartment standing surface and the lowest ceiling obstruction. The 95th percentile stature of the broader land forces population used in these studies was based on the earlier 1997 Land Forces Survey [ref 24] and three other factors: turbulence, night vision goggles (NVGs), and PPE. As well, the SOR stipulates a willingness for the CF to comply with relevant workspace health and safety guidelines for SAR Techs. As discussed earlier, using the 5th to 95th percentile data points will put 10% of the SAR Tech population at risk for MSDs due to imposed awkward postures. The workspace envelope of the FWSAR cabin should ideally allow all SAR Techs, regardless of stature, the ability to perform all operational functions with a minimal need to resort to awkward postures. Because of this, the 99th percentile in stature is chosen as the basis of calculation for cabin height.

The two human factors issues that are important to include in the cargo compartment requirements are stature and PPE as shown in *Table 2* below.

Table 2: Cargo compartment height based on anthropometric considerations.

		95th %	97th %	99th %
Human factors considerations	Stature (cm)	186.2	188.3	191.1
	PPE (cm)	7.6	7.6	7.6
	Total (cm)	193.8	195.9	198.7

PPE: The cargo compartment height must accommodate standard issue aircrew equipment. A total allowance of 7.6 cm is required for apparel, comprising 2.5 cm for footwear and 5.1 cm for the helmet [ref 4].

Turbulence: SAR Techs routinely work in turbulent conditions that produce rapid-onset vertical accelerations and oscillations. Additional headroom clearance is required for the tallest SAR Techs to reduce the risk of neck injury caused by the head striking the ceiling. Although turbulence was not directly measured or assessed in this study, it is reasonable to include some additional vertical clearance between the helmet and the cargo compartment ceiling to provide a margin of safety to account for the potential effect of turbulence. What is in question is the amount of clearance required to minimize the risk of injury. The SOR stipulated 10 cm for this purpose [ref 1]. A reduced value may correspond with increased risk, albeit unquantifiable. There does not appear to be any scientific study that provides guidance on head room clearance in aircraft during turbulent conditions. In the absence of available relevant research, this assigned 10 cm margin is somewhat arbitrary and consequently has been removed from this analysis.

5 Conclusions

A human factors analysis of aircrew operational tasks in a FWSAR aircraft cargo compartment was conducted to address concerns regarding future risk of musculoskeletal injury to SAR Techs. A biomechanical approach was used to quantify injury risk related to the workspace envelope of current CC-130 Hercules and CC-115 Buffalo aircraft. The full range of SAR tasks were recorded by digital video during in flight operations over a period of two weeks at two separate squadron locations. The JOHSC team reviewed the NRC report and the scientific work previously conducted pertaining to the cargo compartment dimensions stipulated in the SOR. Two studies produced by Directorate of Airworthiness and Engineering Support (DAES) were examined which derive the FWSAR aircraft cabin height and aisle width requirements [refs 4 and 9]. In the NRC report, it was suggested that further analysis be undertaken to augment the human factors work previously conducted by DAES. Specifically, NRC recommended that a supplementary study examining working postures assumed by SAR Techs during operational duties was necessary to more fully establish the risk of musculoskeletal injury to SAR Techs in the cargo compartment. It was determined that a quantitative assessment of space-critical aerial delivery tasks and four relevant types of equipment: marine pump, toboggan, equipment bundle, and sea rescue kit would sufficiently demonstrate postural and loading demands.

SAR Techs require reasonable accommodation to their work environment so that they can safely perform their job and maintain effective provision of CF emergency SAR response services. Much of the SAR Techs operational tasks are comprised of lifting, carrying and dragging heavy air droppable equipment. These duties are performed primarily in a dynamic work environment. This report explores many factors during SAR operations that can contribute to the ability of SAR Techs to safely and effectively perform their job. It has been demonstrated through biomechanical analysis and review of the literature that heavy loads combined with change in working posture can have adverse implications on the musculoskeletal structures of the spine. The ability of SAR Techs to maintain upright neutral standing postures while conducting SAR operations would mitigate the risk of exceeding musculoskeletal tissue tolerance levels. Further, being able to stand upright will provide adequate rest recovery, and would further reduce the risk of developing a MSD over time. This study has sought to provide guidance on the minimum cargo compartment space requirements based on operational duties performed by SAR Techs as well as to address concerns regarding future risk of musculoskeletal injury to SAR Techs working in a FWSAR aircraft cargo compartment.

The following are conclusions and recommendations on a cargo compartment workspace envelope for a FWSAR aircraft:

5.1 Cargo door exit and aisle considerations

- The minimum workspace width and length dimensions at the cargo door exit for the preparation and deployment of equipment is currently stated in the SOR as 185 cm X 206 cm. Based on the REBA scores obtained for each of the tasks analyzed, the risk level at these dimensions were high and postural demands placed on SAR Techs were well above those accepted according to industry-standard ergonomics practices.

- The physical workspace should accommodate to the SAR role and not impede already challenging SAR tasks. The present workspace layout at the cargo exit is such that SAR Techs must manoeuvre equipment around a cramped space. Any further reduction in workspace at this location would elicit even more awkward postures.

- Accessible deck space is required for SAR Techs to successfully complete the full range of current FWSAR procedures. This includes the aisle width next to the SAR load which is currently stipulated as 77.5 cm in the SOR. The aisle width must be kept as wide as possible given the constraints of airframe design.

5.2 Cargo compartment height clearance

- A minimum cabin compartment height of 198.7 cm is recommended. The required vertical clearance was based on the 99th percentile male and associated PPE. Some consideration must be given for turbulence, although there does not appear to be valid scientific guidance on clearance height.

- SAR Techs should be provided with the opportunity to maintain as neutral a posture as possible while conducting MMH tasks aboard the aircraft. The benefit of maintaining an upright neutral posture with the back straight is that pressure is evenly distributed over the discs and creeping is minimized. This will result in a reduced MSD.

5.3 Limitations and Assumptions

- This trial used a two-dimensional analysis of SAR postures. One of the limitations of two-dimensional analysis is that it does not adequately capture the full risk exposures such as twisting of the trunk observed during SAR handling tasks. The loading could be modelled using complex combinations of loads.

- The results of the biomechanical analysis are conservative as they do not account for other factors that increase the load experienced by the SAR Techs such as in-flight turbulence and the effect of G loading during aircraft manoeuvring.

- Although aircraft turbulence was not measured directly, some headroom clearance is required for the tallest SAR Techs to reduce the risk of a neck impact injury. A safety margin of 10.0 cm was originally proposed in the SOR but there does not appear to be a valid scientific study supporting this estimate.

5.4 Further Recommendations

- It is highly recommended that a study be undertaken to quantify the affects of turbulence on the vertical displacement of airframe occupants and derive from this a vertical clearance component to account for turbulence.

- It is recommended that a task analysis and link analysis of the entire FWSAR cargo compartment be conducted to ensure that the procedures conducted and equipment utilized by SAR Techs are located in the most optimal position within the airframe based on frequency of use, carry distance, anthropometrics and workplace constraints.

- To mitigate musculoskeletal risk to SAR Techs during manual materials handling tasks, it is advisable that education on proper load handling techniques be administered to SAR Techs.

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Annex A Instrumentation and Assessment Tools

A.1 Instrumentation

A force gauge was used to measure SAR equipment loads and pushing and pulling forces. A Manual Shimpo® digital push-pull force gauge measures the tension or compression applied to a probe with ± 0.2% of full-scale accuracy. This mechanical dynamometer provides the capacity to measure up to 227 kg of force.

A.2 Assessment tools

The REBA developed by Hignett and McAtanmney [ref 14] is a semi-quantitative tool for evaluating postural changes of individuals performing MMH tasks. It is a field tool designed for evaluating tasks that produce dynamic postures with extreme changes in positioning of joint segments, which may expose personnel to risk of a WMSD.

QBack software developed by Queen's University, Kingston Ontario is an analysis tool used to apply the NIOSH guideline on compressive loads associated with MMH tasks [ref 5]. The software is a static biomechanical model that estimates compressive load on the L4/L5 spinal disc and other upper body joints from known input parameters such as the orientation of the segments of the body, as well as, magnitude and direction of the loads in each hand. Tissue loads can be compared with prescribed NIOSH guidelines to estimate the level of risk associated with a MMH task.

Body Sizing System 21st Century (BoSS XXI) system was developed by VisImage Systems Inc., Markham, Ontario [ref 26] and is primarily used to size CF members for uniform and equipment. Specifically, the BoSS XXI is a computer-aided digital system designed to obtain, process and interpret two-dimensional images. Three-dimensional human motion analysis techniques and algorithms are used to produce 38 distinct anthropometric measurements. Precision of the BoSS XXI data was assessed by taking repeated images on a standardized, full-size, plastic mannequin. The BoSS XXI system was validated with direct anthropometric measurements (i.e., weight scale, anthropometers, measuring tape) taken by trained specialists. The system was used to measure 349 subjects (95 females, 254 males) and the data were compared with those obtained in the 1997 Land Forces Anthropometric Survey [ref 24]. The results indicated a standard deviation of 0.07 cm for stature measurements [ref 22] indicating minimal measurement error. It is known that direct measurements produce a small amount of measurement error. The main sources of error specific to two-dimensional image-based anthropometry include resolution, calibration, bone landmark, and modelling techniques. The sources of error produced by image capture can be minimized through higher resolution systems and modelling algorithms. The error produced when measuring segments is also minimal (± 0.4 m) [ref 22].

Annex B Rapid Entire Body Assessment (REBA)

The following postural analysis includes the results of the REBA scores with respective level of risk. The REBA scores for four SAR tasks performed at the ramp and cargo door exits in the Buffalo and Hercules aircraft are provided. The values are based on a composite score that combine two phases of aerial delivery: 1) preparation and 2) deployment. The postural analysis includes task descriptions of selected equipment: marine pump, toboggan, equipment bundle, and sea rescue kit and discussion.

B.1 Marine pump

Task description: The marine pump is air dropped by SAR Techs to vessels that are in distress as a result of taking on water (*see Figure B-2*). The weight of the air droppable pump with parachute (attached by a 600 ft rope) was 70.5 kg.

Preparation: Two SAR Techs transport the pump from stowage to either the ramp or cargo door exit. The SAR Techs lift and carry the pump by the handles along the aisle in a single file and facing forward in the direction of the ramp exit. One SAR Tech normally prepares the pump for airdrop. This involves conducting safety inspections of the parachute, as well as securing the pump with tie downs and quick release straps to the ramp airframe and static line. When the pump has been prepared, the aircrew conduct personal safety checks prior to opening the ramp or cargo door exits. The SAR Techs are attached to safety harnesses. The pump is normally carried with one hand, in single file, to the exit for deployment because of the narrow width of the aisle.

Figure B-2: Pump drop from the cargo door exit in the Buffalo CC-115.

Deployment: When the ramp or cargo door exit is opened the pump is lifted by the SAR Techs and placed as close as possible to the exit. SAR Techs carrying the pump in single file or side-by-side in the direction of the exit depending on which exit used. The SAR Techs use the quick release to disengage the straps securing the pump to the airframe. The pump is then pushed out the exit using the hands or feet.

B.1.1 Posture analysis

The aisle provided limited space for the two SAR Techs to carry the pump. The task of preparing the marine pump for airdrop elicits large ranges of joint motion, and the SAR Techs were unable to maintain neutral body postures during the pump deployment task. There was limited working space to prepare pump equipment particularly at the Buffalo cargo door exit. The ramp and cargo compartment exits were compared between the Buffalo and Hercules aircraft.

Ramp exit (Buffalo CC-115 and Hercules CC-130): The REBA score computed for preparation and deployment was 10.5 for both aircraft ramp exits, indicating a high level of risk. High posture demands were observed especially when the pump is pushed out of the ramp exit. SAR Techs frequently twisted their trunk with lateral bending. Other postures observed were abduction of the arms while twisting the trunk to push the pump forward.

Cargo door exit (Buffalo CC-115): The REBA score computed for preparation and deployment of the pump was 11.5. There was limited workspace near the cargo door exit mainly due to SAR equipment. SAR Techs produced large joint ranges of motion while they lifted and carried the pump between different origins and destinations. SAR Techs were observed frequently twisting their trunk, leaning forward and to one side (lateral bending) while preparing the pump for deployment. The SAR Techs were often observed widening their base of support to maintain balance and stability especially during aircraft banking. When deploying the pump, the SAR Tech sat on the ramp and braced the feet against the pump in a static flexed position (*Figure B-3*). The SAR Tech over extends the arms in order to pull the quick release strap to free the pump. Once the chute was deployed the SAR Tech forced the pump out the cargo door with the feet while the other SAR Tech controlled deployment of the pump.

B.2 Toboggan

Task description: The toboggan is dispatched in a rescue scenario to provide survival equipment (i.e., tents, rations, lanterns, stoves, etc.) for the SAR Techs that are planning to jump into an aircraft crash site. The weight of the toboggan is 137.5 kg. The quick-release mechanism is pulled vertically to waist level. When the call to drop is provided, the toboggan is lifted from one end and then pushed out the exit.

Preparation: Two SAR Techs are required for this task. The SAR Techs lift and carry the toboggan in a single file to the exit where it is lowered and secured to the airframe close to the cargo door or rear ramp exit.

Deployment: Once door or ramp is opened the SAR Tech releases the safety strap and pushes the toboggan out of the exit.

B.2.1 Posture analysis

Ramp exit (Buffalo CC-115): The REBA score computed for preparation and deployment was 11 and indicates a very high level of risk. The narrow aisle did not permit the SAR Techs access on either side of the toboggan. The two SAR Techs pushed the toboggan forward and backwards across the ramp and these motions produced extreme forward flexion of greater than 60 degrees.

Figure B-3: Deployment of toboggan from cargo door exit in the Buffalo CC-115.

Cargo door exit (Buffalo CC-115): The REBA score computed for preparation and deployment was 12 and indicates a very high level of risk. This task was performed with the trunk twisted due to a narrow aisle and the length of the toboggan. The narrow aisle forced the SAR Tech to lift above the waist to rotate it into position for deployment *(Figure B-4).* The working space restrictions elicited asymmetrical postures. The SAR Tech had to lift the toboggan load while pulling backwards with the arms and twisting the upper body. The SAR Tech lifted the toboggan above waist level forcing the shoulders to elevate with static forward flexion at the trunk. When the quick release strap was pulled, the SAR Tech forcibly pushed the toboggan forward and down towards the exit. The back straightened and then extended backwards in an exaggerated posture to deploy the toboggan.

B.3 Equipment bundle

Task Description: The equipment bundle drop with cargo net is dispatched in a rescue scenario to provide miscellaneous survival equipment (i.e., medical supplies, survival equipment, climbing gear, etc.) for use by the SAR Techs. The weight of the bundle including the net, equipment and parachute is 71.5 kg.

B.3.1 Postural analysis

Ramp exit (Buffalo CC-115 and Hercules CC-130): The REBA score computed for preparation and deployment was 10.5 and 12.5, respectively, and indicates a high to very high level of risk. From a semi-seated position the SAR Tech remained in a forward flexion position over the bundle. Once the parachute was deployed, the SAR Tech stood up from a semi-seated to a standing position while pushing the bundle forward for deployment out the exit. As with the Buffalo ramp exit, postures are awkward and force the SAR Tech to assume a flexed position while twisting the trunk (*Figure B-5*). A forward flexed position was required while pushing the bundle out the rear ramp.

Figure B-4: Bundle drop from ramp and cargo door exit in the Buffalo CC-115.

Cargo door exit (Buffalo CC-115): The REBA score computed for preparation and deployment was 11.5 and indicates a very high level of risk. The hip was bent laterally in order to secure the bundle to the airframe. SAR Techs were observed maintaining a forward flexion while twisting the trunk during the bundle drop.

B.4 Survival Rescue Kit

Task Description: The sea rescue kit is dropped to sea to persons who are abandoning a sinking vessel. The kit is placed differently depending on a cargo-door or a rear-facing door deployment. For a rear-facing door deployment the four-bundle kit (combined weight of 46 kg) is laid out two-on-two for a cargo-door deployment. Each bundle kit is physically jettisoned separately at 1 to 2 second intervals.

Preparation: Two SAR Techs manually manoeuvre the four bundles from stowage to either the ramp or cargo door exit. The SAR Techs carry the bundles independently. Two of the SAR Techs prepared the kit by stacking them side by side or in a 2 by 2 formation. Safety inspections and securing the kit are conducted. Once the kit has been prepared and preparatory procedures completed, the aircrew conduct personal safety checks prior to opening the ramp or cargo door exits. The SAR Techs are also attached to safety harnesses prior to preparing the kit for airdrop.

Figure B-5: Deployment of sea rescue kit from the ramp exit in the Buffalo CC-115.

B.4.1 Postural analysis

Ramp exit (Buffalo CC-115 and Hercules CC-130): The REBA score computed for preparation and deployment was 12 and 12 and indicates a very high level of risk. The SAR Tech maintained a forward flexed position while pushing the bundle kit forward out the rear ramp.

Cargo door exit (Buffalo CC-115): The REBA score computed for preparation and deployment was 12 and indicates a very high level of risk. The SAR Techs were observed twisting the trunk, bending forward and laterally in order to complete this task. While the SAR Techs secured the survival equipment to the floor their posture continually changed from neutral to forward flexion. The SAR Tech maintained a forward flexed position while pushing the bundle kit out the cargo door (*Figure B-5*). This task required the SAR Tech to push forward the four-bundle kit out the cargo door. This was done by the SAR Tech remaining in a kneeling or semi-kneeling (squatted) position while the other SAR Tech remained standing in a forward flexed position looking out the cargo door to confirm the survival kit drop. The SAR Tech pushed the kit out the door by raising the arm in an exaggerated position. Only one kit could be dropped at a time due to space restriction.

List of acronyms

AL	Action Limit
AOR	Area of Responsibility
CF	Canadian Forces
CFB	Canadian Forces Base
CFEME	Canadian Forces Environmental Medicine Establishment
DAR	Director Air Requirements
DAES	Director Aerospace Engineering Support
DPGR	Director of Personnel Generation Requirements
DRDC	Defence Research and Development Canada
DSSPM	Director of Soldier Systems Program Management
FW	Fixed-Wing
FWSAR	Fixed-Wing Search and Rescue
G	Gravitational
HREC	Human Research Ethics Committee
JOHSC	Joint Operational Human Sciences Centre
L4/L5	Fourth and fifth lumbar vertebrae
MMH	Manual Materials Handling
MPL	Maximal Permissible Limit
MSD	Musculoskeletal Disorder
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council Canada
NVG	Night Vision Goggles
PPE	Personal Protective Equipment
PFMP	Physical Fitness Maintenance Program
REBA	Rapid Entire Body Assessment
RW	Rotary Wing
SAR	Search and Rescue
SAR Techs	Search and Rescue Technicians
SOR	Statement of Operational Requirements
T&R	Transport and Rescue
WMSD	Workplace Musculoskeletal Disorder

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Human Factors Analysis of Aircrew Operational Tasks in a Fixed−Wing Search and Rescue Aircraft Cargo Compartment (U)
Analyse des facteurs humains liés aux tâches opérationnelles qui sont exécutées par les membres d'équipage dans la soute des avions de recherche et de sauvetage (U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

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(U) The Joint Operational Human Sciences Centre (JOHSC), at the request of Director Air Requirements (DAR), conducted a human factors analysis of aircrew operational tasks in a Fixed−Wing Search and Rescue (FWSAR) aircraft cargo compartment. The aim of this study was to provide guidance on minimum cargo compartment dimensions based on operational duties performed by Search and Rescue Technicians (SAR Techs). Specifically, it includes an analysis of the entire workspace envelope, to determine compartment length, width and height requirements. A secondary aim was to address concerns regarding future risk of musculoskeletal injury to SAR Techs working in the cargo compartment of a FWSAR aircraft.

The full range of operational tasks performed by SAR Techs in the current FWSAR aircraft was observed at squadrons in Trenton, Ontario and Comox, British Columbia. Space critical aerial delivery tasks and four relevant types of equipment were selected for analysis, including postural and spinal load assessments of manual materials handling (MMH) and anthropometry based on current SAR Tech demographics. Potential risk of musculoskeletal injury to SAR Techs during operational tasks was evaluated. Results were used to provide guidance based on ergonomics principals, standards in the industry, and current operational FWSAR procedures. Relevant anthropometry, secular growth trends, personal protective equipment (PPE) and workspace dimensions were considered.

Based on a 99th percentile SAR Tech male (BoSS XXI), a minimal cabin compartment height of 198.7 cm, or rounded up 200 cm, is recommended. However, this value does not account for any head room clearance required under turbulent conditions. Rapid Entire Body Assessment (REBA) and QBack analysis results indicate that the postural and loading demands were well above those accepted based on ergonomics practice and occupational limitations according to the Institute for Occupational Safety and Health National Institute (NIOSH) guidelines. Reductions in potential musculoskeletal injury could be achieved by allowing SAR Techs to carry loads in a neutral (i.e.: upright) posture. To mitigate musculoskeletal risk, it is advisable that education on proper load handling techniques be administered to SAR Techs.

(U) Le Centre interarmées des sciences humaines opérationnelles (CISHO), à la demande du Directeur, Besoins aérospatiaux (DBA), a effectué une analyse des facteurs humains liés aux tâches opérationnelles qui sont exécutées par les membres d’équipage dans la soute des avions de recherche et de sauvetage (SAR). L’étude avait pour objet d’établir des lignes directrices quant aux dimensions minimales de la soute compte tenu des tâches opérationnelles exécutées par les techniciens de recherche et de sauvetage (Tech SAR). Plus particulièrement, l’étude comprend une analyse de l’ensemble de l’espace de travail afin de déterminer la longueur, la largeur et la hauteur que devrait avoir la soute. Un objectif complémentaire consistait à se pencher sur le risque futur que les Tech SAR travaillant dans la soute d’un avion SAR subissent des blessures musculo−squelettiques. On a observé toute la gamme de tâches opérationnelles exécutées par les Tech SAR dans les avions SAR actuels, dans les escadrons de Trenton (Ontario) et de Comox (Colombie−Britannique). On a choisi des tâches dont l’exécution en vol nécessitait un espace critique ainsi que quatre types d’équipements pertinents pour les analyser, notamment évaluer l’effort postural et vertébral lié à la manutention manuelle des matériaux (MMM) et établir une anthropométrie fondée sur des données démographiques

courantes des Tech SAR. On a également évalué le risque que des Tech SAR subissent des blessures musculo−squelettiques durant l’exécution de tâches opérationnelles. Les résultats ont été utilisés pour établir des lignes directrices fondées sur des principes d’ergonomie, des normes de l’industrie et les procédures d’exploitation actuelles des avions SAR. On a tenu compte de données anthropométriques pertinentes, des tendances de la croissance séculaire, de l’équipement de protection individuelle (EPI) et des dimensions de l’espace de travail.
En se fondant sur le 99e percentile de Tech SAR masculin (BoSS XXI), on recommande que la soute mesure au moins 198,7 cm de hauteur, valeur pouvant être arrondie à 200 cm. Toutefois, cette valeur ne tient pas compte du dégagement au−dessus de la tête qui est nécessaire en présence de turbulences. Les résultats des analyses effectuées à l’aide d’outils d’évaluation (Rapid Entire Body Assessment [REBA] et QBack) indiquent que l’effort postural et vertébral nécessaire était bien supérieur à celui prescrit par les lignes directrices sur les pratiques d’ergonomie et les restrictions professionnelles publiées par l’Institut national pour la santé et l'hygiène professionnelles (INSHP). Il est possible de réduire les risques de blessures musculo−squelettiques en permettant aux Tech SAR de transporter des charges dans une posture neutre (c’est−à−dire debout). Pour atténuer le risque de blessures musculo−squelettiques, il est conseillé d’enseigner aux Tech SAR les bonnes techniques de manutention des charges.

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(U) Aircrew Operational Tasks; Fixed−Wing Search and Rescue Aircraft

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